

Mars Trace Gas Mission Science Rationale & Concept

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Presentation to the NRC Decadal Survey
Mars Panel

10 September 2009

Background (1 of 2)

MEPAG Science Analysis Group Activities (2006-2007)

- Science Analysis Group (SAG-1), chaired by C.B. Farmer
Strategic Mission to study atmospheric photochemistry and aeronomy, following up on Solar System Exploration Decadal Survey recommendation
⇒ **MAVEN and TGE selected to compete for 2011 launch as a Mars Aeronomy Scout**
- Science Analysis Group (SAG-2), chaired by W. Calvin
Defined 3 mission concepts, one of which was a Trace Gas mission to follow up on potential exchanges of methane between the atmosphere and subsurface, implying a dynamic Mars with the possibility of a biochemistry
⇒ **NASA forms Science Definition Team for a Mars Science Orbiter focused on trace gas detection and mapping**

2013 MSO Science Definition Team (SDT)

- Telecons/meetings October–December 2007
- Final written report January 2008
⇒ **Aeronomy Mars Scout (MAVEN or TGE) slipped to 2013 launch**
- Report to MEPAG February 2008
⇒ **MAVEN selected for launch in 2013**

Background (2 of 2)

2016 MSO SDT Telecon Update:

⇒ *Earth-based observations confirm methane detection, report variability*

- Focused on minimum payload required to follow up on reported methane discoveries, for possible low-cost NASA mission or joint ESA-NASA mission
- Telecon held February 17, 2009
- Briefing to NASA MEP and to MATT-3

ESA-NASA discussions on Joint 2016 Mission (2009)

Joint Instrument Definition Team (JIDT) studies Trace Gas instruments for ExoMars orbiter/carrier; re-affirms need for both detection of broad suite of gases in atmosphere and mapping of key trace gases

⇒ *Earth-based observations confirm methane detection, report variability*

⇒ *ExoMars slips to 2018 opportunity*

Study of joint mission combining Trace Gas orbiter with technology drop-off package is initiated (August, 2009)

Agenda

- Science Rationale & Objectives for a Trace Gas Mission
- A Mission Concept (NASA only) to Achieve those Objectives

What Science Questions are Raised by Methane Detection?

Current photochemical models cannot explain the presence of methane in the atmosphere of Mars and its reported rapid variations in space and time. Neither appearance nor disappearance can be explained, raising the following scientific questions:

- Is there ongoing subsurface activity?
 - Are there Surface/near-Surface Gas Reservoirs (particularly ice)? Where are they?
 - What is the nature of gas origin: geochemical or biochemical?
 - Are other trace gases present? What are the isotopic ratios?
 - Nature of the methane source requires measurements of a suite of trace gases in order to characterize potential biochemical and geochemical processes at work
 - What processes control the lifetimes of atmospheric gases?
 - Time scales of emplacement or activation and modification (seasonal, annual, episodic, longer term)
 - Role of heterogeneous chemistry: reactions on surface or airborne dust and ice
 - Atmospheric-surface exchange and atmospheric transport
- ⇒ ***What is the inventory, transport, and photochemistry of the Mars atmosphere? Note: It's not just about methane!***

A Trace Gas Mission must provide:

- A *comprehensive survey of both known gases* (H_2O , H_2O_2 , CO , etc.), as well as to *improve detection limits by an order of magnitude or more* on gases not yet observed.
- A *definitive statement* about whether or not methane is still present in the atmosphere and characterize whatever variability it has. However, a detailed inventory of atmospheric gases and their isotopologues would be a *major advance* in our understanding of the recent history and climate of Mars *whether or not methane is detected*.
- Characterization of the *roles that aerosols and temperature play* in controlling atmospheric composition.
- All atmospheric fields required (temperature, density/pressure, wind, aerosol concentration) to enhance our ability to *understand and to simulate for science and engineering* the Mars atmosphere.

Atmospheric Composition

Atmospheric evidence for present habitability

Key measurement objectives:

Photochemistry (H_2O_2 , O_3 , CO , H_2O)

Transport (CO , H_2O)

Isotopic Fractionation (isotopomers of H_2O and CO_2)

Surface exchange (CH_4 and H_2O)

Inventory (HO_2 , NO_2 , N_2O , C_2H_2 , C_2H_4 , C_2H_6 , H_2CO , HCN , H_2S ,
 OCS , SO_2 , HCl)

Measurement goals:

Solar occultations to obtain sensitivity of 1–10 parts per trillion

Limb-geometry mapping at sensitivity of 1–10 parts per billion with
latitude/longitude/altitude/local time coverage

⇒ Would significantly improve knowledge of atmospheric composition
and chemistry

⇒ Could lead to identification of source regions

Atmospheric State

Climate processes responsible for seasonal / interannual change

Key measurement objectives:

Wind velocity

Water vapor and atmospheric temperature without influence of dust

Diurnal coverage of all parameters

Vertical profiles of all parameters

Continue climatology monitoring

Measurement goals:

2-D wind velocity, temperature, aerosol optical depth, water vapor at

5 km vertical resolution over broad height range

diurnal coverage twice per martian season

85% or better coverage along orbit

⇒ Extend record of climatology to characterize long-term trends

⇒ Validate and significantly improve models of transport and state

Surface Change Science

Recent processes of surface-atmosphere interaction

Key measurement objectives:

- Geologic context of potential localized trace gas sources
- Aeolian features (dust devil tracks, streaks, dust storm changes)
- Gullies, avalanches, dune motions
- Formation of small impact craters over time

Measurement goals:

- 1 meter resolution sufficient for these goals

- ⇒ Understanding active processes and the role of volatiles
- ⇒ Exchange of volatiles between high latitudes and atmosphere

Trace Gas Measurement Objectives

Detection:

- Would require very high sensitivity to the following molecules and their isotopomers: H_2O , HO_2 , NO_2 , N_2O , CH_4 , C_2H_2 , C_2H_4 , C_2H_6 , H_2CO , HCN , H_2S , OCS , SO_2 , HCl , CO , O_3
- Detection sensitivities of 1-10 parts per trillion

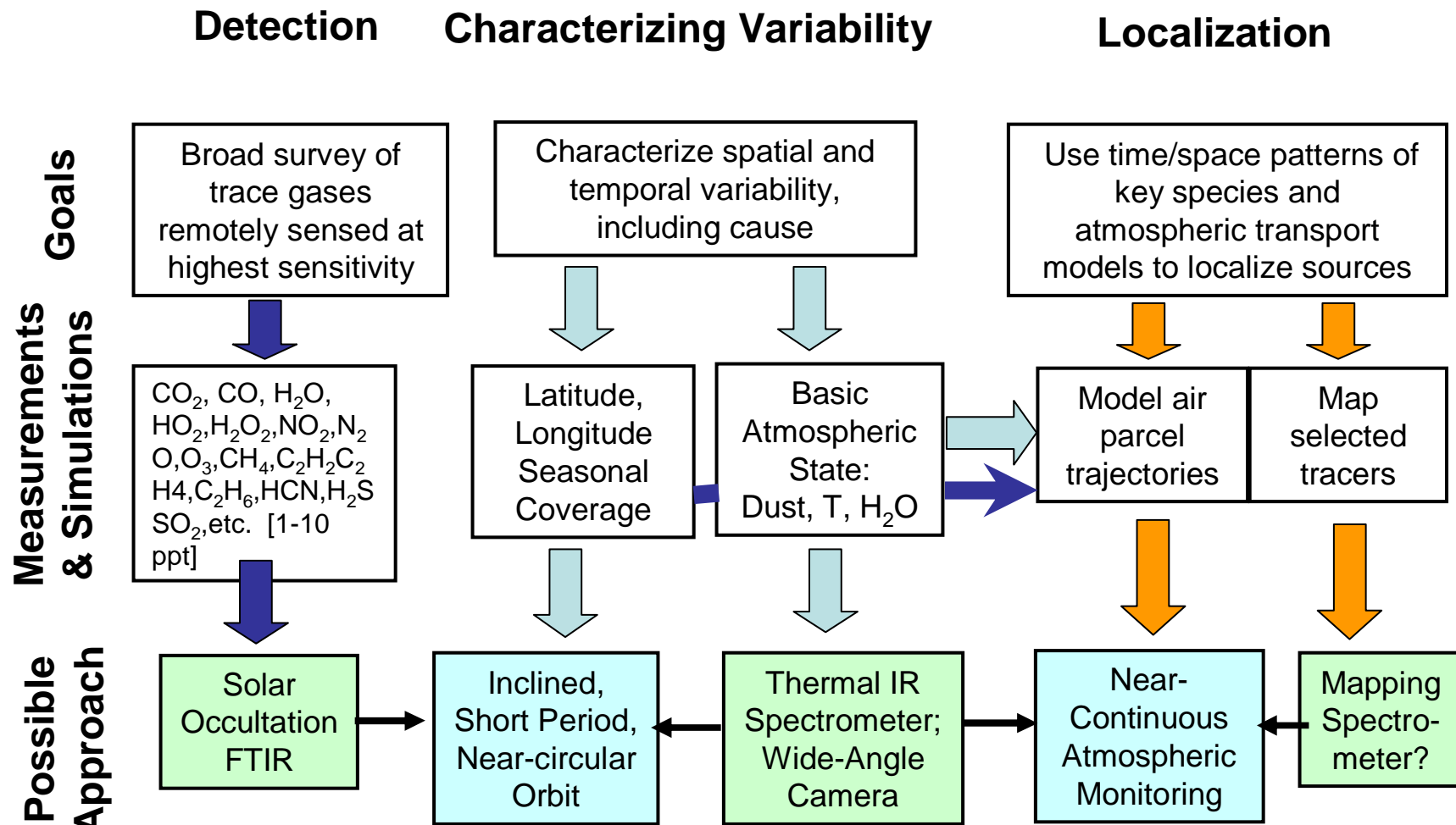
Characterization:

- Spatial and Temporal Variability: Latitude-longitude coverage multiple times in a Mars year to determine regional sources and seasonal variations (reported to be large, but still controversial with present understanding of Mars gas-phase photochemistry)
- Correlation of concentration observations with environmental parameters of temperature, dust and ice aerosols (potential sites for heterogeneous chemistry)

Localization:

- Mapping of multiple tracers (e.g., aerosols, water vapor, CO , CH_4) with different photochemical lifetimes and correlations would help constrain model simulations and points to source/sink regions
- To achieve the spatial resolution required to localize sources might require tracing molecules at the ~ 1 part per billion concentration
- Inverse modeling to link observed concentration patterns to regional transformations (e.g., in dusty air) and to localized sources would require simulations using circulation models constrained by dust and temperature observations

Trace Gas Measurement Requirement Flow-Down



Sample “strawman” Payload (existence proof)

- Solar occultation spectrometer(s)

Atmospheric composition (broad spectral range and high resolution)
Mapping key species (narrower spectral range)

- Sub-millimeter spectrometer

Wind velocity through Doppler shift
Water vapor, temperatures, etc., without influence from dust
Map key species

- Wide-angle camera (MARCI-like)

Daily global view of surface and atmospheric dust and clouds

- Thermal-IR spectrometer

Daily global observations of temperature, dust, ice, water vapor
Direct comparison to previous climatology record

- High-resolution camera (as resources permit)*

Imaging of possible local sources and active surface processes

**Prime difference between TGM concept and earlier MSO*

Orbit characteristics:

Near-circular at low altitude (300-400 km)

- Would allow best *coverage mapping*
- Would allow most solar occultation opportunities (*most sensitive detection*)
- Orbit altitude might be increased at some point for planetary protection

High inclination ($\sim 74^\circ \pm 10^\circ$)

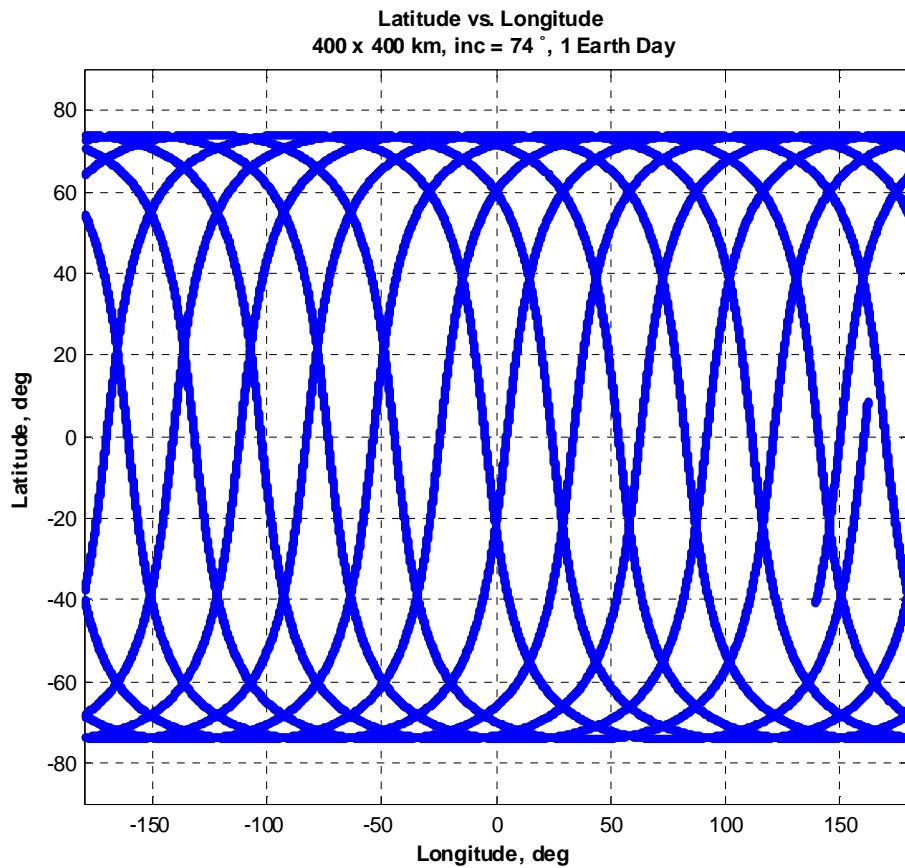
- Compromise between *global coverage* and faster *precession of local time* and more uniform latitude distribution of solar occultation points
- Science would require *full diurnal cycle* in less than a Martian season

Mission duration (1 Mars year)

- Full seasonal coverage

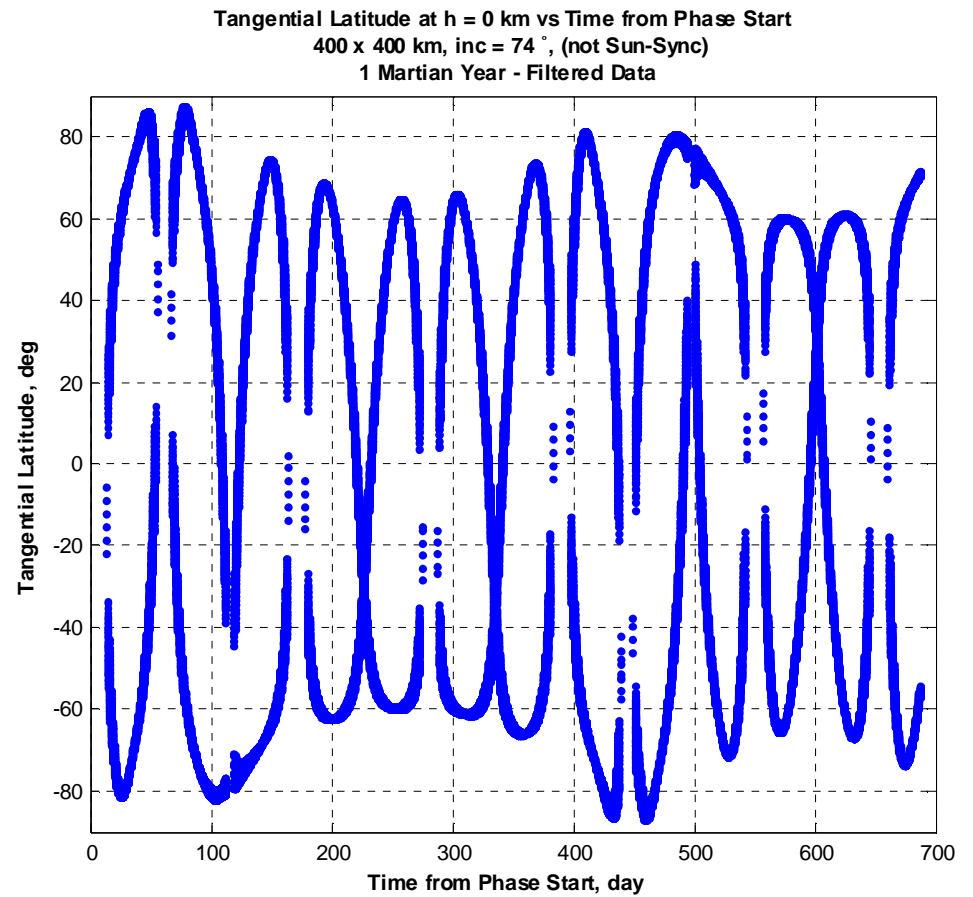
Orbit tracks for one day

Good global mapping



Solar occultations for one year

Good latitude distribution





2016 TGM Mission Implementation Concept

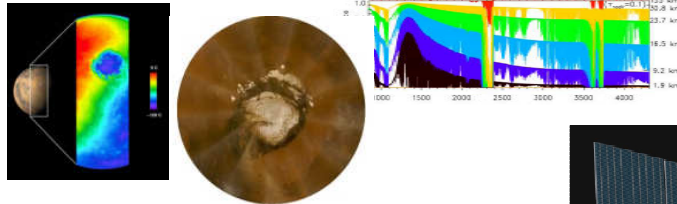
OBJECTIVES

Perform Trace Gas / Mapping (TGM) Science

*Atmospheric Composition and State
Detection, Mapping, and Characterization*

Telecom Infrastructure for future missions

Proximity UHF and deep space X band links



Nadir- and limb-pointing capability

UHF proximity telecom 250 Mb/sol

X-Band deep space telecom > 2 Gb/day

Data storage 64 Gb

EOL power 1500 W

Cost effective monopropellant propulsion

5 year lifetime, 10 years consumables

FLIGHT SYSTEM

PAYLOAD

Notional Instruments*

Solar occultation (FTIR spectrometer)

Atmospheric composition

Wide-angle camera (MARCI-like)

Global view of surface, dust and clouds

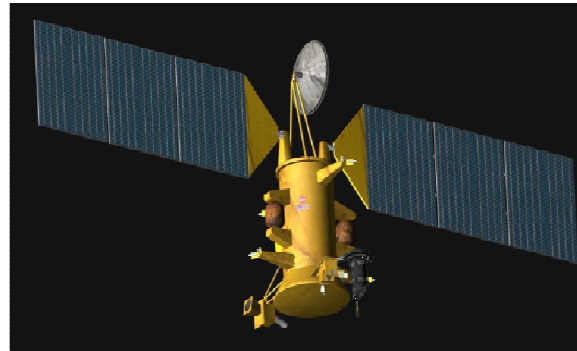
Thermal-IR spectrometer (TES-like)

Temperature, dust, ice, water vapor climatology

Mapping Spectrometer (Multiple Spectrum

Measurement Approaches)

Water vapor, Wind, Temperature



S/C Bus Dry Mass 1100 kg

Science Payload* 115 kg

Propellant 1915 kg

Total Wet Mass 3130 kg

LV Capability 3330 kg

(assuming an Atlas-V 411)

MASS SUMMARY

MISSION DESIGN

Proposed Launch Date January 2016

Launch C_3 13.9 km²/s²

V_{inf} 3.8 km/s

Aerobraking Duration 6 to 9 months

Start Science Observation March – June 2017*

Science Orbit Walking, Inclination 74°

Science Emphasis Phase ~2 yrs, 400 x 400 km

Relay Emphasis ~2 yrs, 400 x 400 km



Notional Cost through Launch (RY \$M)*

Development Cost ~ 535

Launch Vehicle 215

Cost-through-Launch ~ 750

Proposed Key Milestones

Mission Concept Review ~Sept 2010

PDR Dec 2012

CDR Sept 2013

Sys Integration Review July 2014

Fight Readiness Review Dec 2015/Jan 2016

COST & SCHEDULE

***Several partnering approaches are being considered**

Pre-decisional for planning and discussion purposes only

Summary:

- TGM would enable *significant new science* and provide *key infrastructure* elements
- TGM science objectives *not covered* by any other proposed mission (including MSR)
- 2016 is *avored launch opportunity* for TGM:
 - Would provide needed telecom support for other future missions
 - Would minimize gap in atmospheric monitoring
 - Possible synergy with proposed MAVEN extended mission

Back-Up

MSO SDT Membership:

Michael Smith, Chair, NASA Goddard Space Flight Center

Don Banfield, Cornell University

Jeff Barnes, Oregon State University

Phil Christensen, Arizona State University

Todd Clancy, Space Science Institute

Phil James, University of Toledo (retired)

Jim Kasting, Pennsylvania State University

Paul Wennberg, Caltech

Daniel Winterhalter, JPL

Michael Wolff, Space Science Institute

Rich Zurek, JPL (Mars Program Office)

Janis Chodas, JPL (MSO Project Manager)

Tomas Komarek, JPL (MSO Mission Concept Manager)

JIDT Membership:

ESA Participants

- Augustin Chicarro
 - *ESA - Co-Chair*
- Jean-Loup Bertaux
 - *Service D'Aeronomie, CNRS*
- Frank Daerden
 - *BIRA/IASB*
- Vittorio Formisano
 - *IFSI Roma (I)*
- Gerhard Neukum
 - *Freie Universitaet Berlin*
- Albert Haldeman
 - *EXM/ESA*

NASA Participants

- Richard Zurek
 - *JPL (MPO) - Co-Chair*
- Mark Allen
 - *JPL*
- R.Todd Clancy
 - *Space Science Institute*
- Jim Garvin
 - *NASA GSFC*
- Michael Smith
 - *NASA GSFC*
- Tom Komarek
 - *JPL (MPO)*